Next Generation Curve Tracer Revolutionizes Failure Analysis

Application Note B1505A-2

Introduction

Analog curve tracers have traditionally been used for failure analysis and acceptance testing of power devices because of their convenient ability to vary the voltage output simply by rotating a knob.

However, modern power devices such as power MOSFETs or IGBTs (Insulated Gated Bipolar Transistors) require current measurement capabilities that are more precise than those available on analog curve tracers in order to verify parameters such as leakage current. Also, the extraction of electrical parameters like threshold voltage (Vth) and transconductance (gm) are necessary to verify the functionality of many new types of power devices.

Traditional analog curve tracers were originally developed to observe the IV curves of bipolar junction transistor (BJT) power devices. This makes it difficult for them to meet the measurement requirement of modern power devices due to their limited measurement functionality and relatively poor measurement accuracy. Also, conventional curve tracers do not have any automated data analysis capabilities and their dependence on antiquated floppy disk drives for data
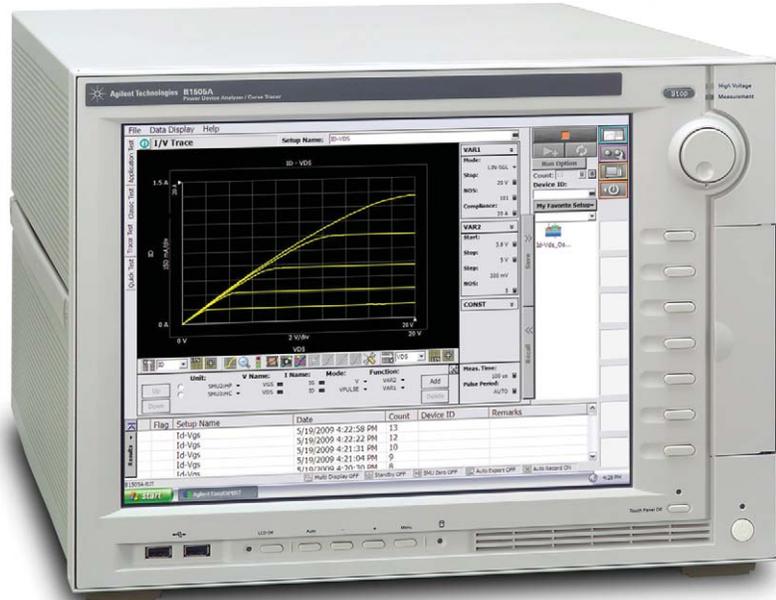
transfer makes it difficult to create reports in modern PC-based work environments.

The Agilent B1505A Power Device Analyzer/Curve Tracer is a revolutionary solution for conventional curve tracer users. The B1505A's measurement circuitry is based on Source Measure Unit (SMU) technology, which is the industry standard for precision semiconductor device parametric measurement. The B1505A's SMU voltage and current ranges have been expanded to be comparable range to those of conventional curve tracers (3000 V and 20 A). SMUs have the additional advantage of possessing multiple measurement ranges with auto ranging capability,

which enables precise low current measurement over a wide dynamic measurement range.

EasyEXPERT software, which is resident on the B1505A, provides an intuitive and flexible data management and analysis environment on the B1505A's Microsoft® Windows® based platform. In addition, EasyEXPERT supports a true curve tracer mode with knob sweep capability. These features make the B1505A much more than just a replacement for conventional curve tracers.

This application note describes in detail how the B1505A can help you to improve the efficiency of your failure analysis.

Agilent Technologies

Precise and Flexible Measurement Capability

Figure 1 shows the simplified circuit diagram of a conventional analog curve tracer. The curve tracer has two main signal sources: a collector supply to sweep bias on the collector and a step generator to sweep the bias on the base terminal. In a traditional curve tracer, a cathode ray tube (CRT) is used to display the IV curve. The voltage applied to the collector terminal is used to deflect an electron beam horizontally and voltage across a shunt resistor (to measure collector current) is used to deflect it vertically. From the names of these signal sources it should be obvious that curve tracers were designed to observe the IV curves of bipolar junction transistors. Even in more modern digital curve tracers the basic architecture of analog curve tracers was retained, with the major modification being that the deflection plates were replaced with analog to digital converters to support digital acquisition of the vertical bias and collector current.

In contrast to conventional curve tracers, the B1505A Power Device Analyzer/Curve Tracer's design is based on well-established SMU technology. SMUs have been the standard tool for semiconductor material and device electrical characterization for over 25 years. The SMU combines a programmable voltage (or current) source with a current (or voltage) meter, providing precision measurement capability over wide current and voltage ranges. This enables the user to measure over wide ranges very quickly, from small leakage currents (pico-Amps) up to large currents (tens of Amps).
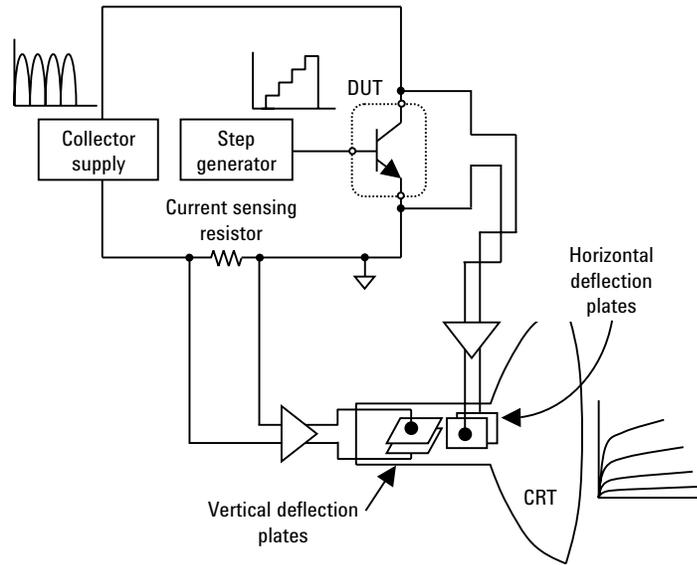

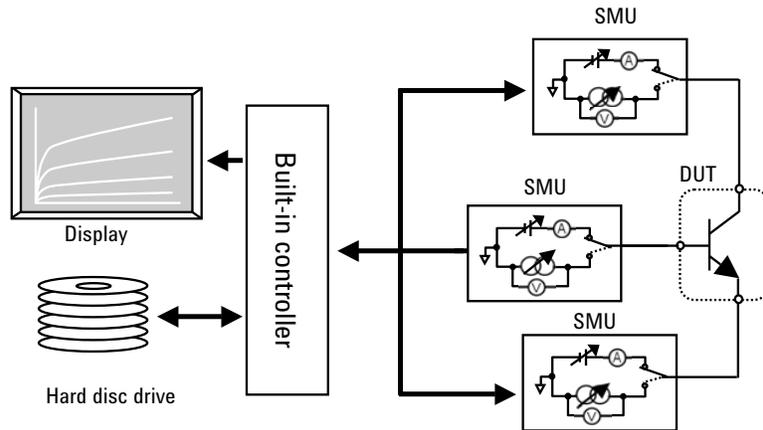Figure 1. Simplified curve tracer circuit diagram .

Figure 2. The B1505A architecture is based on SMU technology.

The high power SMU (HPSMU) has a range that covers 200 V and 1 A range. The high current SMU (HCSMU) has a range that covers up to 20 A (@ 20 V). The high voltage SMU (HVSMU) has a range that covers up to 3000 V (@ 4 mA). Table 1 summarizes the key SMU specifications.

This broad range of measurement capabilities enables the B1505A to perform measurements not possible with conventional curve tracers, such as precision leakage current measurements of gate dielectrics and sub-threshold characteristics of power MOSFETs.

SMUs have the unique capability to measure current or voltage while simultaneously sourcing either voltage or current, which permits the measurement of many different device parameters without the need to change any device connections. Figure 3a shows the connections required to measure drain current versus drain voltage (Id-Vds) characteristics of a power MOSFET using a curve tracer; however, in order to measure drain current versus gate voltage (Id-Vgs), the device connections have to be changed as shown in Figure 3b. In contrast, the SMU-based B1505A can measure both Id-Vds and Id-Vgs without the need to change any cables (Please see Figure 4.)

Table 1. Output and measurement ranges of the SMUs supported by the B1505A

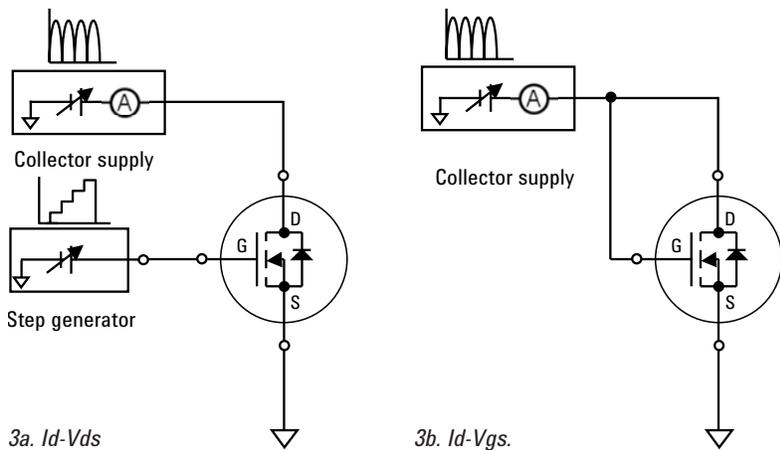| Type of SMU	Output range	Measurement resolution
HPSMU	± 200 V, ± 1 A	2 µV, 10 fA
HCSMU	-40 V to 40 V, -1 A to 1 A -20 V to 20 V, -20 A to 20 A (Pulse only)	200 nV, 10 pA
HVSMU	-3000 V to 3000 V, -4 mA to 4 mA -1500 V to 1500 V, -8 mA to 8 mA	200 µV, 10 fA

3a. Id-Vds   *3b. Id-Vgs.*

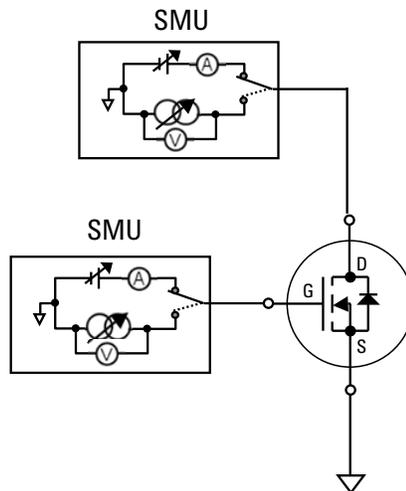*Figure 3. Connection diagram for curve tracer Id-Vds and Id-Vgs measurements.*

Figure 4. Connection diagram for B1505A Id-Vds and Id-Vgs measurements.

Of course, in some cases the SMU type has to be changed depending on the measurement range required. For example, for the Id-Vds measurement the HCSMU must be connected to the drain terminal to supply the desired amount of drain current. However, for a drain to source breakdown voltage (BVdss) measurement, the HVSMU must be connected to the drain terminal to supply sufficient high voltage to reach the breakdown condition (Please see Figures 5a and 5b). Agilent can provide a module switching solution so that both of these measurements can be done without having to change any cabling connections. Figure 5c shows a schematic diagram of the module selector unit.

The module selector permits switching between an HVSMU, HCMU and HPSMU; it is controlled by the EasyEXPERT software that is resident on the B1505A.

Agilent also provides the N1259A packaged part test fixture, which is designed for safe high power measurement in conjunction with the B1505A. This test fixture prevents accidental electrical shock via an interlock function that does not allow the B1505A to force more than 42 V unless the fixture lid is closed. Figure 6 shows a photograph of this test fixture.

Agilent supplies an inline package socket module (P/N: N1259A-010) with the N1259A that allows user to measure TO-220 and TO-3P type packaged power devices. In addition, Agilent provides a universal socket module (P/N: N1259A-011) that allows you to develop custom socket modules to measure virtually any package type. A nice feature of the N1259A test fixture is that it is large enough to accommodate large DUTs such as IGBT modules or Intelligent Power Modules (IPMs).

The test fixture supports the module selector option, so operators can execute many different measurements without the need to change the cabling.

EasyEXPERT, the test software resident on the B1505A, not only provides a comprehensive measurement environment but it also offers numerous capabilities that improve the efficiency of failure analysis. The key features of the B1505A's EasyEXPERT software will be discussed in the following sections.

5a. Id-Vds measurement with HSCMU

5b. BVdss measurement with HVSMU

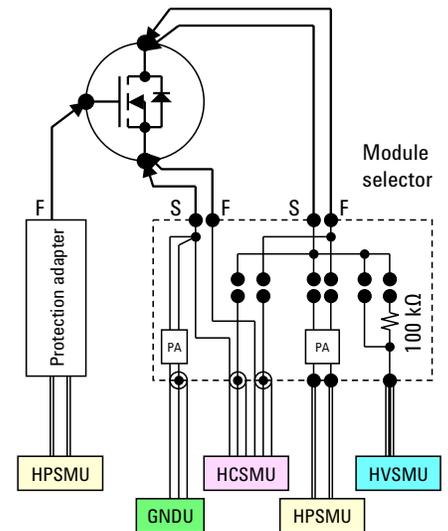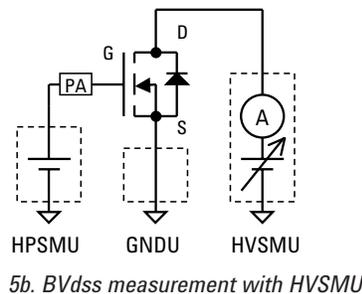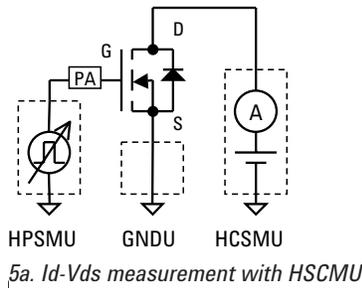5c. Block diagram of the modular selector

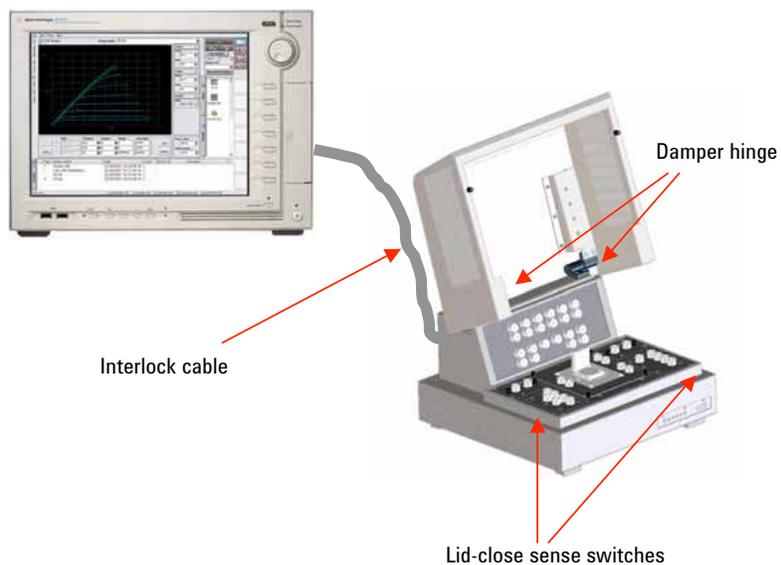Figure 5. Automating connections using the module selector unit.

Figure 6. The N1259A test fixture supports the easy and safe measurement of high power devices.

Tracer Test Mode Provides Convenient Curve Tracer Functionality

The B1505A has a knob sweep function that provides easy and intuitive operation the same as a curve tracer. The function is called the "Tracer Test Mode." The operation of the Tracer Test Mode will be explained in this section using a power MOSFET (part number 2SK3745) as an example.

Figure 7 shows the connections between the terminals of the test fixture and the device.

The 2SK3745 MOSFET is inserted into the N1259A opt 010 inline package socket module (3 pin).

The Tracer Test Mode provides a predefined suite of the most common measurement setups.

The following is a list of these setups.

- MOSFET
  - Drain current to source-to-drain voltage: ID-VDS
  - Drain current to source-to-gate voltage ID-VGS
  - Off state drain leakage current to source-to-drain voltage: ID(off)-VDS,
  - Drain to source breakdown voltage: BVDSS

- Diode
  - Forward biased IV characteristics: IF-VF
  - Reverse biased IV characteristics: IR-VR

- IGBT
  - Collector current to emitter-to-collector voltage: IC-VCE
  - Collector current to emitter-to-gate voltage: IC-VGE
  - Off state collector current to emitter-to-collector voltage: IC(off)-VCE
  - Collector to emitter breakdown voltage: BVCES,

- BJT
  - Collector current to emitter-to-collector voltage: IC-VCE
  - Collector current to emitter-to-collector voltage (base open): IC-VCEO
  - Collector to emitter breakdown voltage (base open): BVCEO
  - Collector current to base-to-collector voltage (emitter open): IC-VCBO,
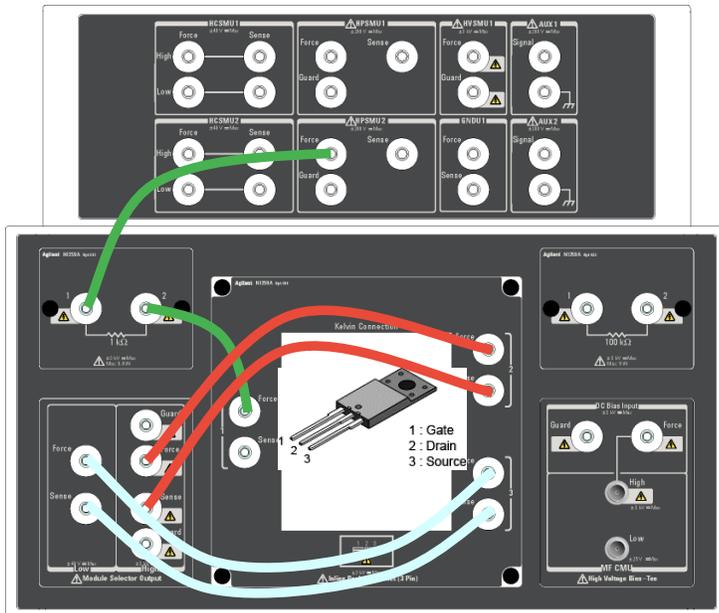 - Collector to base breakdown voltage (emitter open): BVCBO

Figure 7. Power MOSFET measurement connection example.

As an example, here are the steps to execute an Id-Vds measurement using the preset setup.

1. Click the preset button located in the bottom right area of the display (Label 1 of Figure 8).

2. Select "ID-VDS" from the list displayed after selecting the "MOSFET" category (Label 2 of Figure 8).

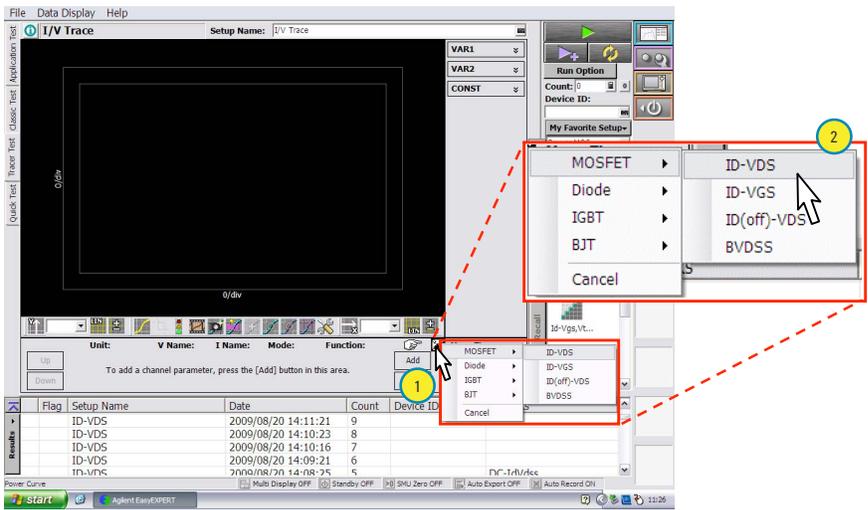3. Change the output mode of the HCSMU drain bias from "VPULSE" to "V" (Label 3 of Figure 9).

4. Set the current compliance of the drain bias source, VAR1, to 1 A (Label 4 of Figure 9). Note that after doing this the vertical display scale automatically changes to the same value as the new compliance value.

5. Enter a start voltage for the sec-ondary gate voltage sweep, VAR2, of 3.5 V (Label 5 of Figure 9).

6. Enter a VAR2 stop voltage of 5.5 V (Label 6 of Figure 9).

7. Click the "Repeat" button to start the sweep (Label 7 of Figure 9). Initially the start voltage and stop voltage VAR1 values are both "0V," so only a single point measurement with Vd = 0 V will keep repeating.
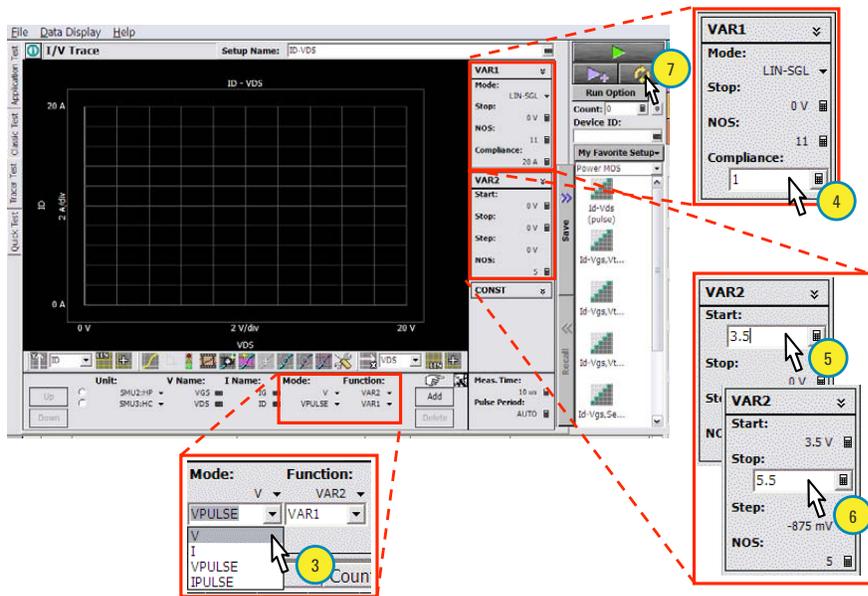
8. Select the VAR1 "Stop" voltage so that it can be controlled by rotating the knob (Label 8 of Figure 10).

9. Rotating the knob now provides interactive control of the stop volt-age, and the trace displayed on the screen will grow and shrink in cor-respondence with the knob rota-tion. Clockwise rotation increases the value and counterclockwise rotation decreases it (Label 9 of Figure 10).

Figure 8. Select preset setup for Id-Vds measurement.

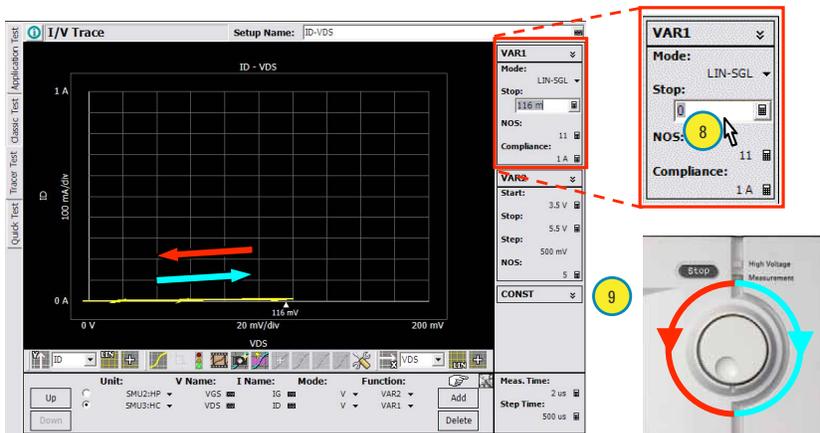Figure 9. Set parameters for Id-Vds measurement and start measurement.
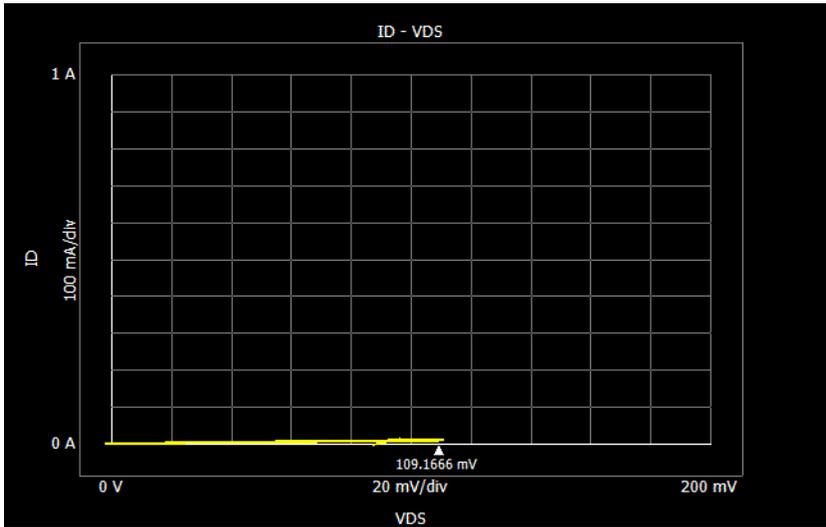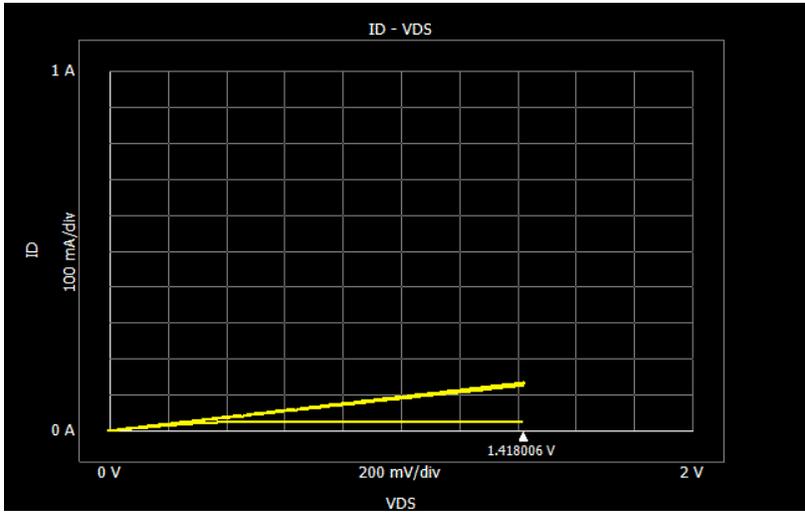

Figure 10. Control the drain bias sweep by rotating the knob.
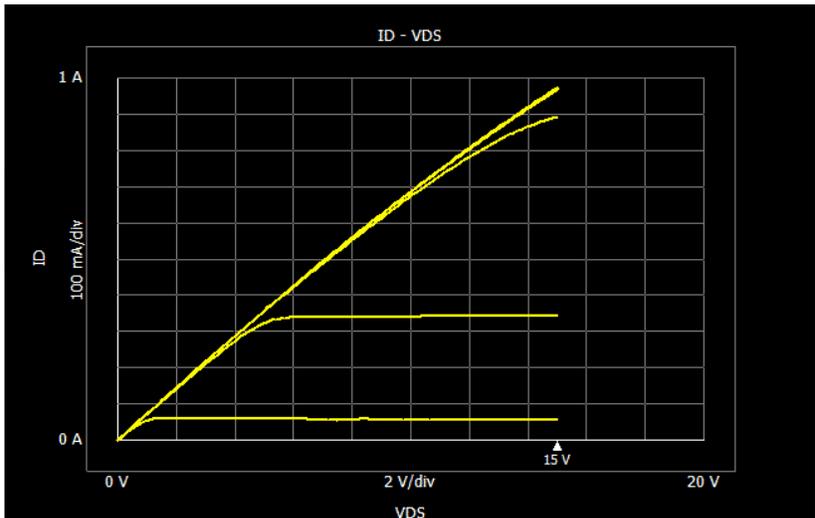
10. Note that as the stop voltage
    is increased the horizontal axis
    automatically changes if the
    trace reaches the scale limit
    (Figures 11a, 11b and 11c). In
    contrast, for conventional curve
    tracers the scale has to be
    changed manually.

11a. 200 mV full scale

11b. 2 V full scale

11c. 20 V full scale

Figure 11. Automated scaling during a sweep.

11. The measurement can be stopped by clicking the "Stop" button (Label 11 of Figure 12) or by pressing the "Stop" button on the touch panel front screen of the B1505A. The trace measurement data is automatically stored into the built-in EasyEXPERT database after terminating a measurement. The measurement setup is also stored into the database, which makes it easy to review and re-execute the measurement later. This auto store function can be enabled or disabled by selecting the "Run Option" button.

This example has shown the typical procedure to perform a simple sweep measurement in Tracer Test Mode. As described here, the Tracer Test Mode provides an ease-of-use that is comparable to or better than of conventional curve tracers.
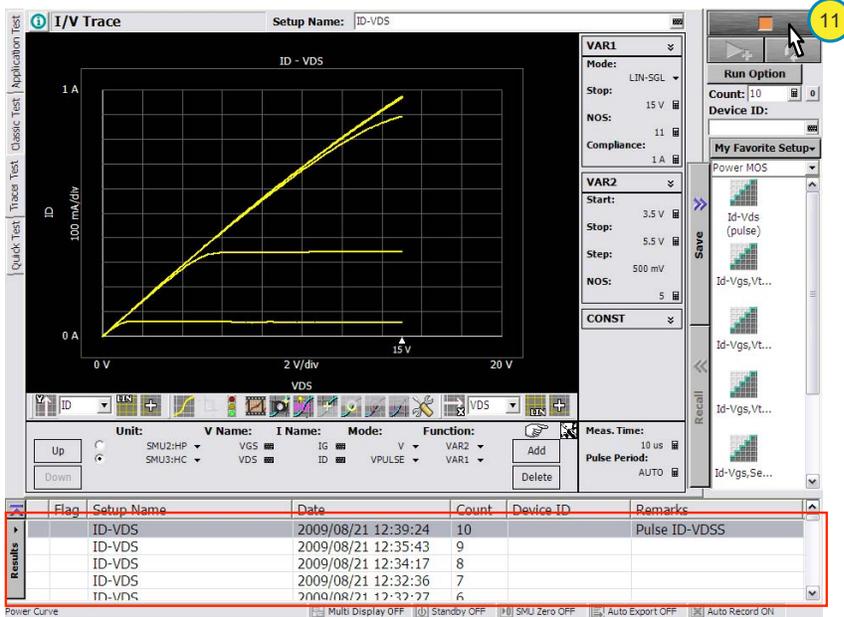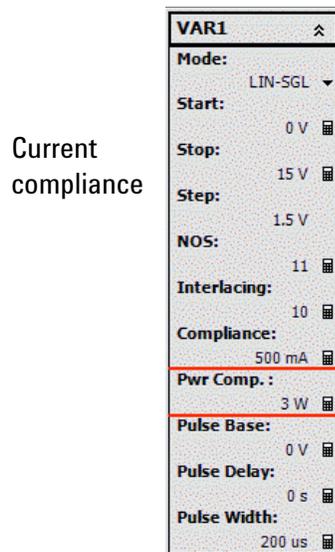

Figure 12. Stopping the measurement and storing the result into the built-in database.

Other Functions to Improve Failure Analysis Efficiency

In addition to its curve tracer functionality, the Tracer Test Mode has other useful features that make failure analysis easier.

One such feature is the compliance function, which can prevent unexpected device damage caused by applying too much current or voltage to the DUT. The B1505A supports two types of compliance: source compliance and power compliance. Figure 13a shows the compliance setup for the VAR1 channel. The current compliance limits the maximum current supplied by the SMU.

When the current reaches the specified compliance value, the measurement will continue to repeat under whatever bias conditions are necessary to maintain the current at a level lower than that of the compliance level (Please see Figure 13b). In addition to source compliance the user can also specify power compliance. This function keeps the total applied power under whatever limit is set as the power compliance value (Please see Figure 13c). If both source and power compliance are specified, then the measurement will limit at whatever is the lower of these two values. The compliance functions can be individually set for each SMU.

Figure 13. Current compliance and power compliance function.

Current compliance

13a. Current compliance and power compliance setup
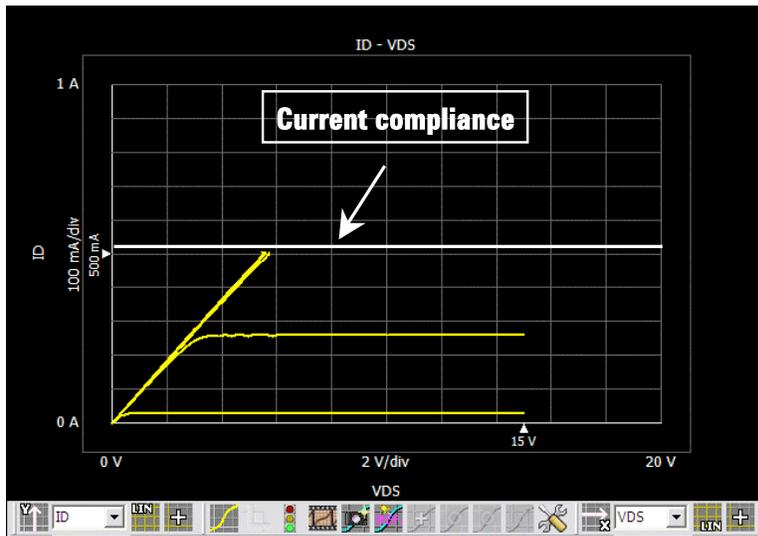
13b. Id-Vds curve when Id reaches its compliance level.
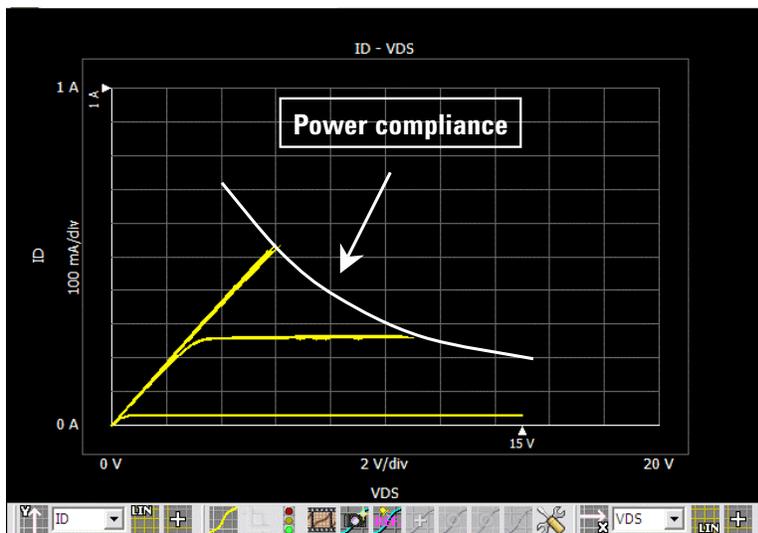
13c. Id-Vds curve when the total power reaches its compliance level.

For curve tracers, the maximum current that can be applied to a device is limited by a series resistor with a discrete resistance values. In contrast, SMU compliance can be set to any arbitrary value within the SMU's output range. This provides the user with maximum flexibility while still preventing inadvertent device damage.

In addition to the above, the B1505A's Tracer Test Mode provides various tools to improve the graphical display. Some of these include: the ability to zoom in on a selected area using the mouse, the ability to change the axes' polarity to compare different types of devices, and the ability to display data on either linear or log scales to observe trace behavior over multiple decades. For example, it is easy to compare the characteristics of P type FET and N type FETs or PNP and NPN BJTs by simply reversing the polarity of the axes. Also, log scaling can be used to extract parameters such as the diode emission coefficient from IV plots with exponential characteristics.

Besides these basic graphical capabilities, other new functions are available that significantly improve efficiency. These new capabilities will be discussed in subsequent sections and illustrated using actual measurement data.

Snapshot tool

The snapshot tool is an extremely useful data storage feature of the B1505A. In this example Id-Vds curves measured by both DC and pulsed bias will be compared on the B1505A's screen using this tool.

First, an Id-Vds curve measured with DC bias is captured using the snapshot tool. The measurement setup is the same as in the previous example. The Id-Vds curve performed with DC bias is changing over time due to self-heating effects. In order to compare this Id-Vds curve with one made using pulsed bias, you only need to click on the camera icon to capture the current trace into memory. The captured trace is displayed in blue (Please see Figure 14).
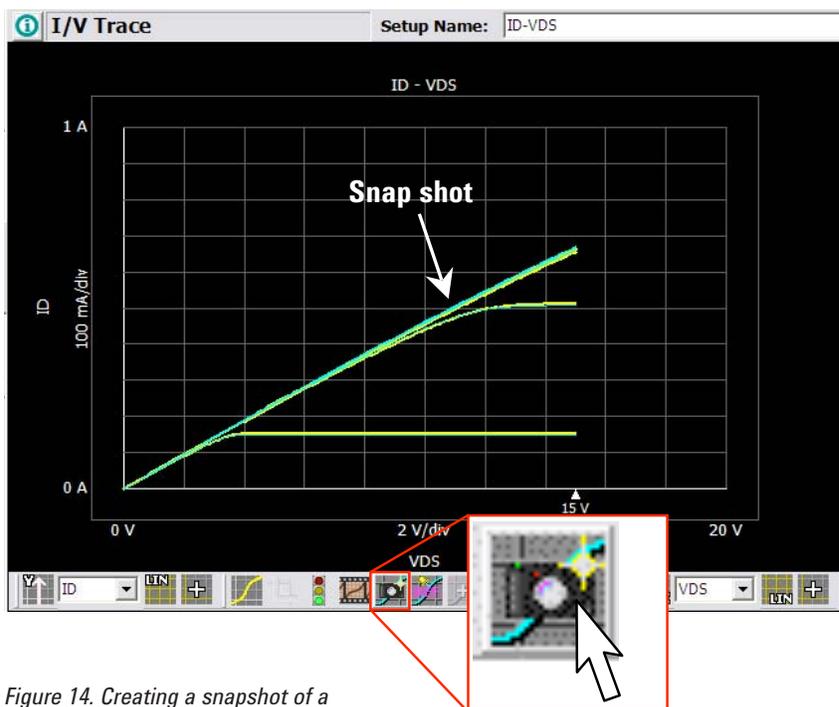

Figure 14. Creating a snapshot of a displayed curve.

Next the measurement is aborted by clicking the "Stop" button and the stop voltage value of the VAR1 sweep variable is set to "0 V." The VAR1 variable is then changed from "V" to "VPULSE" mode as shown in Figure 15. By changing the drain bias from DC to pulsed, the self heating effect is eliminated. Now the pulsed bias measurement can be executed by clicking the "Repeat" button and rotating the knob to increase the drain bias. The trace created using the pulsed bias is overlaid on to the captured trace, permitting the differences between the DC and pulsed measurements to be observed immediately on the B1505A's screen (Please see Figure 16).

The snapshot tool can capture multiple traces, and the user can chose any trace from the list of captured traces as a reference (Please see Figure 17).

On conventional curve tracers, the user has to take photographs of the screen to compare traces measured under different conditions. Unfortunately, it is difficult to compare traces accurately using photographs. The Tracer Test Mode snapshot tool enables the user to compare traces on the screen directly and to see the differences precisely.
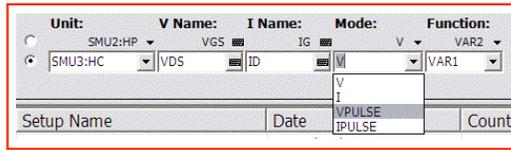

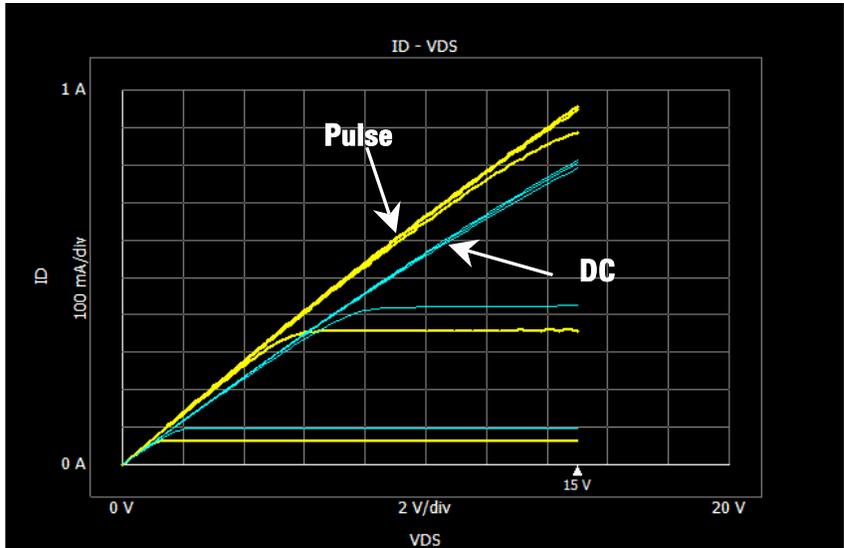Figure 15. Changing constant drain bias to pulsed bias..

Figure 16. Comparison of traces measured using DC and pulsed bias.
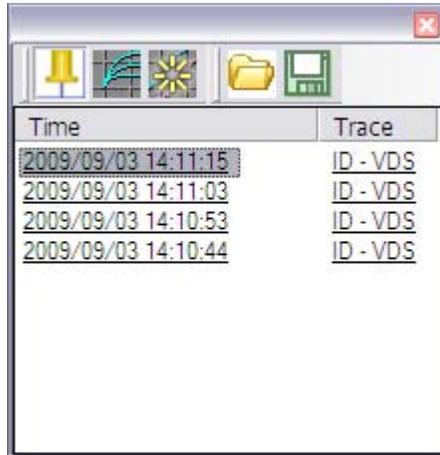

Figure 17. Using the snapshot tool to compare multiple traces.

Marker and Quick Analysis tools

A marker function is also available for simple and quick analysis. Simply click the marker icon to enable the marker function and then click any location on the trace. The value of horizontal axis and vertical axis will be displayed on the screen (please refer to labels 1 to 3 of Figure 18). The marker function can also be used on captured traces in conjunction with the snapshot tool. This makes it easy to compare numerical values taken from different traces directly.
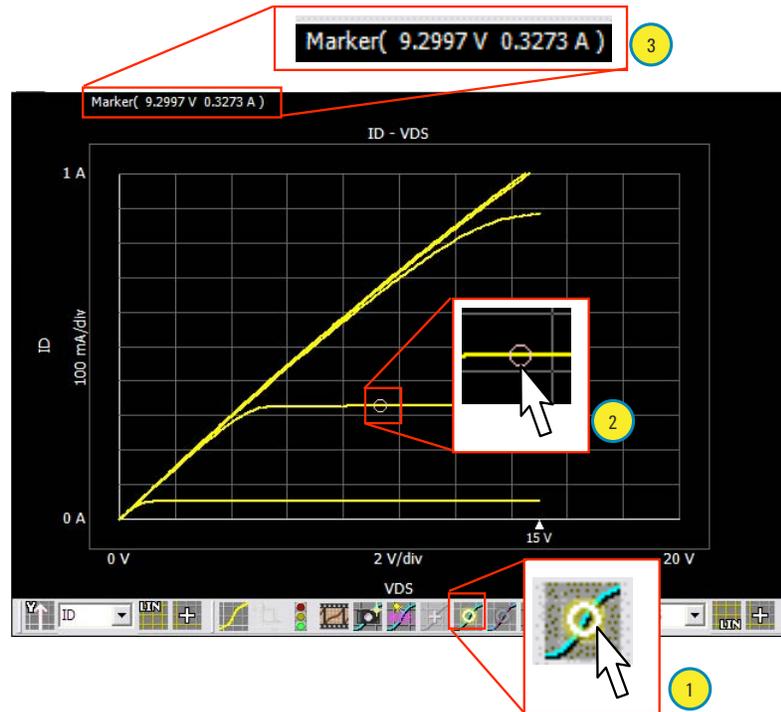

Figure 18. Enabling the marker function.

There are also built-in functions to draw tangent lines and regression lines. The tangent line function draws a tangent line at the marker position as shown in Figure 19a. Figure 19b shows an example of a regression line drawn as defined by the trace selected area. Both functions display the intercept points on the horizontal and vertical axes and line gradient. On a conventional curve tracer, the user has to select a point to draw the line, tilt it manually, and then read out these parameters by visually observing the screen. Obviously, it is very easy to make mistakes using this procedure. In contrast, the quick analysis functions of the B1505A's Tracer Test Mode draw the lines at precisely specified points of the measured data and automatically extract the line parameters. This guarantees repeatable and consistent measurement results.
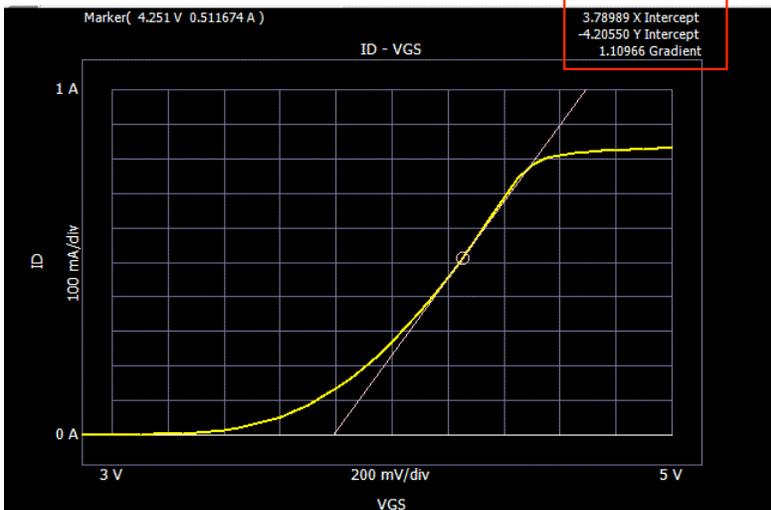
19a. Tangent line
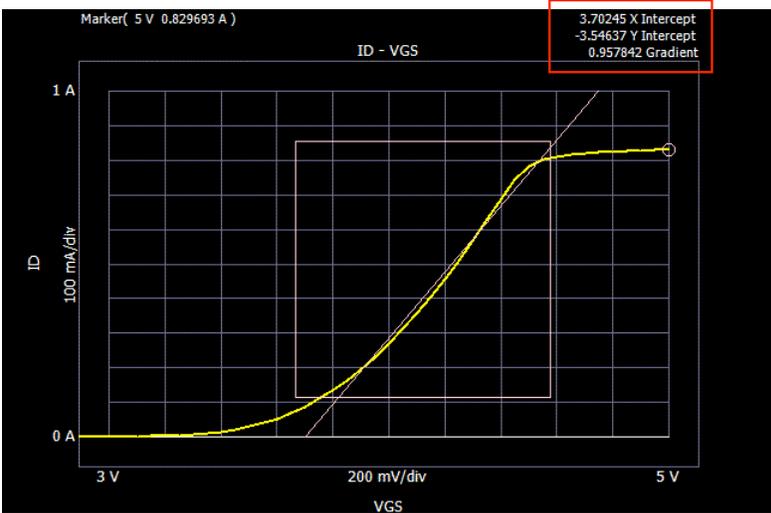
19b. Regression line

Figure 19. Using the quick analysis functions to draw tangent lines and regression lines automatically .

Stoplight tool

In addition to supporting source and power compliance functions as previously mentioned, the B1505A supports a stoplight tool that allows the user to visually define forbidden regions on the screen. To illustrate the use of this feature, a BVdss measurement will be used as an example.

When making a BVdss measurement, the stoplight function is useful to avoid device damage due to excessive current caused by rotating the knob too far. The stoplight function causes the measurement to abort as soon as the quantity under measurement enters the forbidden area as shown in Figure 20. This area can be defined by using the mouse after first enabling this function by clicking the stoplight button.

Since the breakdown current can increase suddenly as it reaches breakdown voltage, when using a conventional curve tracer the user has to be very careful when operating the knob. The B1505A stoplight function eliminates the danger of accidental device damage by providing a visual means to define forbidden areas, thereby improving measurement efficiency.
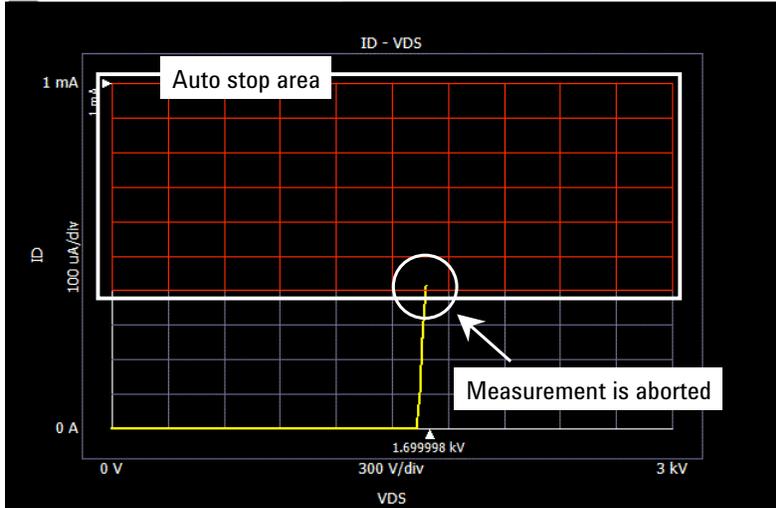

Figure 20. Using the stoplight function to prevent device damage.

Auto-record tool

The auto-record tool is a unique feature of the B1505A Tracer Test Mode. This function keeps a continuous record of the measurement being made so that measurement data is not lost even if the device is inadvertently damaged or destroyed. The trace record tool will also be illustrated using a drain-to-source breakdown voltage (BVdss) measurement.

In addition to enabling data recovery, the auto-record tool can also capture transient phenomena that occur just before breakdown, as these can easily be missed when the user is rotating the knob quickly. In the case of conventional curve tracers, the user has to shoot a video to capture these types of abrupt events. The Tracer Test Mode's auto-record tool provides a much more convenient means to accomplish this same task.

The B1505A Tracer Test Mode automatically records the results of most recent measurement. The user can replay these results by clicking the trace recorder button on the tool bar located at the bottom of the screen (Label 1 of Figure 21). Options to replay step by step or continuously with a specified interval (Label 2 of Figure 21) are available. The user can select specific points on the data record using the sliding bar (Label 3 of Figure 21).

The Tracer Test Mode's unique features free the user from worrying about losing measurement data or missing a transient event due to inadvertent errors that can occur when rotating the knob.
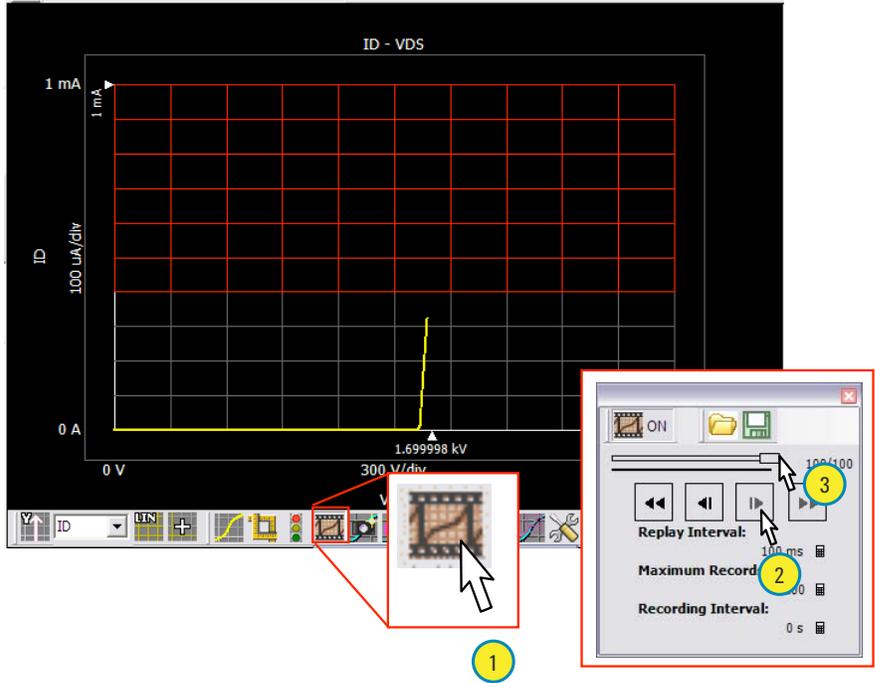

Figure 21. Replaying a trace using the trace replay function.

Quick and Easy Automated Data Analysis

In addition to emulating curve tracer operation, the B1505A has the capability to automatically execute very complicated analyses.

A Classic Test Mode is available that provides measurement functionality equivalent to that of existing semiconductor device or parameter analyzers. Besides supporting sweep measurements, it also supports time domain sampling measurements that permit characterization of the transient device response. The Classic Test Mode also permits control of measurement parameters like measurement range and integration time, which enables the user to obtain more precise measurement results than are available in Tracer Test Mode. Moreover, auto analysis functions are available that enable the user to develop customized and complicated analysis procedures to extract device parameters.

Figure 22 shows a Classic Test Mode example of extracting emitter resistance (Re) from BJT measurements. In this example, a regression line is drawn between two predefined points corresponding to base current (Ib) values of 40 mA and 100 mA. Re is calculated by inverting the slope of this line and it is displayed as an extracted parameter. Figure 23 shows how this analysis was set up. First, the auto analysis setup is defined to draw a line as shown in Figure 23a. Next, a function to calculate Re is defined as a user function as shown in Figure 23b.
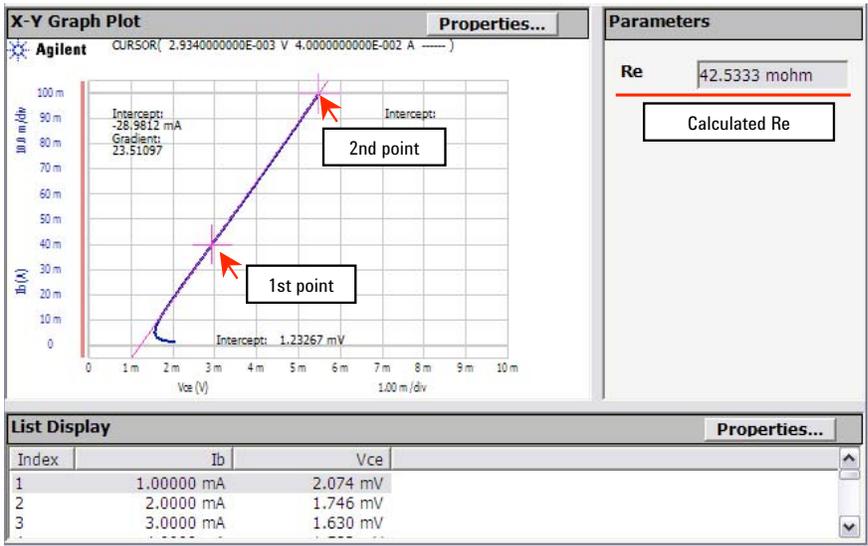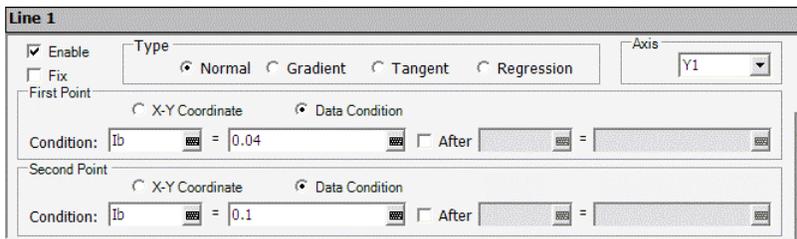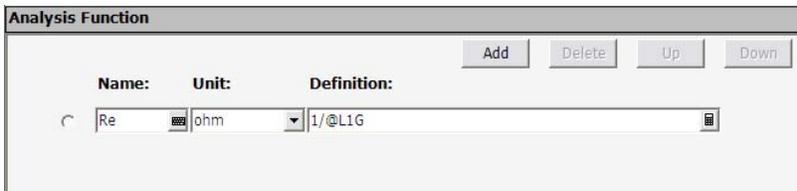

Figure 22. Automated emitter resistance (Re) extraction using the Classic Test Mode.

23a. Auto analysis setup to draw line between specified two points.

23b. User defined function to calculate "Re" from the line drawn by the auto analysis function.

Figure 23. Sample setup to extract the Re of a BJT.

Figure 24 shows another Classic Test Mode example to extract a MOSFET threshold voltage. In this example, the transconductance (Gm) is calculated from the gradient of the Id-Vgs curve, the maximum value of Gm is determined, and a tangent line is drawn at this point. The Vth is then calculated by determining the point on the drain voltage curve corresponding to place where the tangent line intercepts the horizontal axis.

The auto analysis feature has many functions available that make it easy to extract various semiconductor device parameters. These capabilities are the same as those of Agilent semiconductor parameter analyzers, which have been industrial standards for more than 15 years.

The B1505A makes it easy for the curve tracer users to convert measurement setups created in the Tracer Test Mode into equivalent Classic Test Mode setups. The user merely has to save a Tracer Test Mode measurement setup into a "My Favorite Setup" directory, and this setup can then be loaded directly into Classic Test Mode (please see Figure 25). Using this feature, curve tracer users can quickly create Classic Test Mode setups from a familiar curve tracer mode environment.
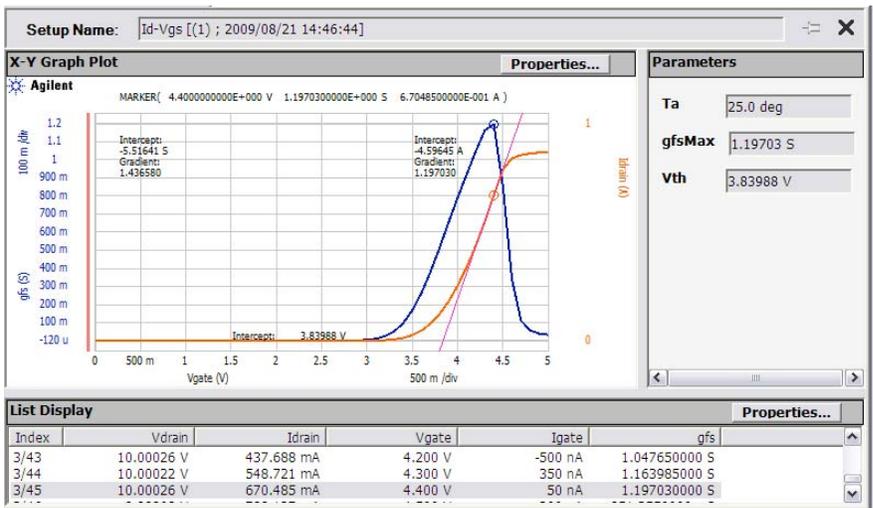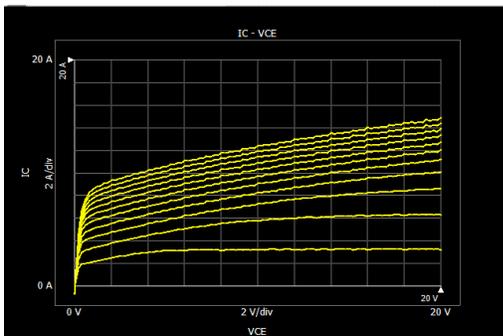

Figure 24. MOSFET Vth extraction example.
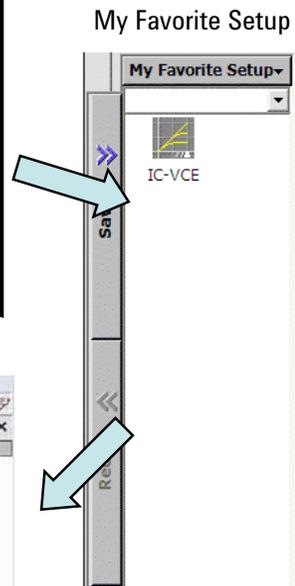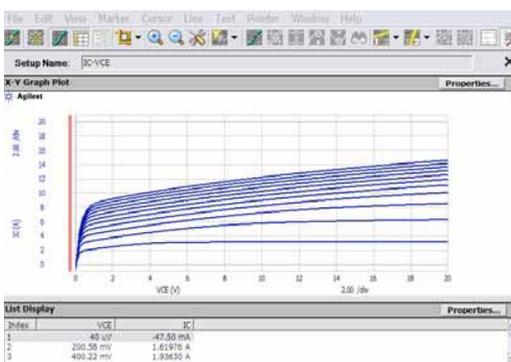
Tracer test

My Favorite Setup

Classic test

Figure 25. Transferring setups from tracer test to classic test using "My Favorite Setup".

EasyEXPERT comes standard with over 40 pre-defined, user-modifiable measurement setups in its Application Test Mode library, and these cover most device types (including power devices) as shown in Figure 26. This library of furnished application tests is very easy to use, and only requires the user to fill in the key measurement parameters. This significantly reduces the time and effort required to make productive measurements.

Just like for the Tracer Test and the Classic Test Modes, setups created in the Application Test Mode can also be stored into a "My Favorite Setup". Using the stored setups, automated execution of multiple tests is possible. The Quick Test Mode of the B1505A allows the user to execute a series of measurements in arbitrary order without the need to write any sort of a program. Figures 27 and 28 show an example of using setups stored in "My Favorite Setup" in Quick Test to perform automated testing.

EasyEXPERT also has the ability to control semiautomatic wafer probers. By combining wafer prober control with the Quick Test Mode function, it is possible to perform multiple testing on various devices across the wafer. EasyEXPERT has built-in drivers for the most popular semiautomatic wafer probers.

As has been described in this section, EasyEXPERT has powerful capabilities for automated analysis on not just discrete devices but also for the automated testing of multiple devices across an entire wafer. These capabilities and the precision measurement resources of the B1505A enable it to replace not only curve tracers but also rack and stack systems to perform failure analysis and power device parameter extraction.
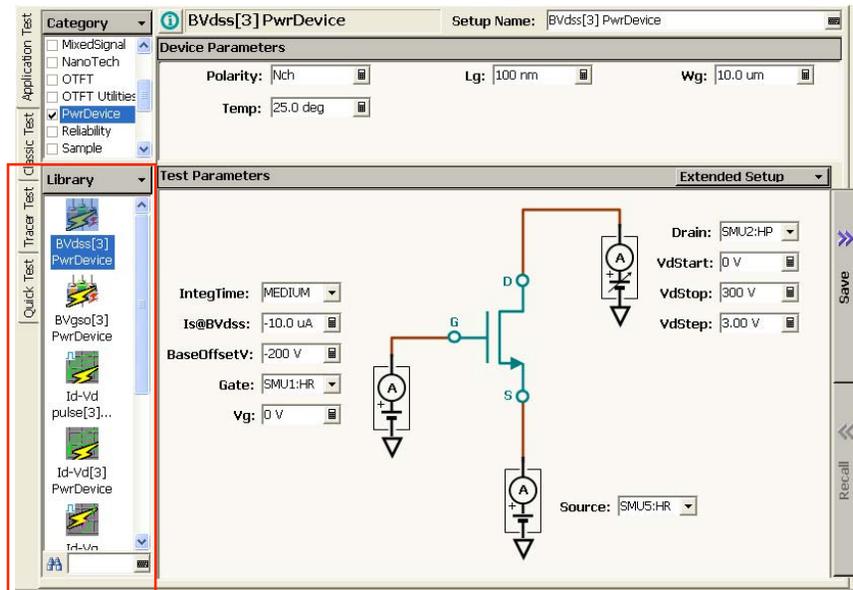

Figure 26. Examples of the power device application library.
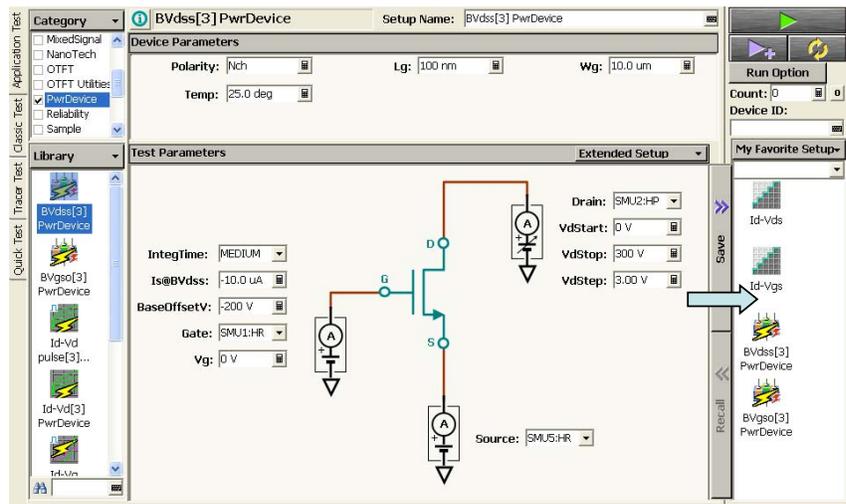

Figure 27. Classic Test and Application Test setups can be stored into a My Favorites directory.
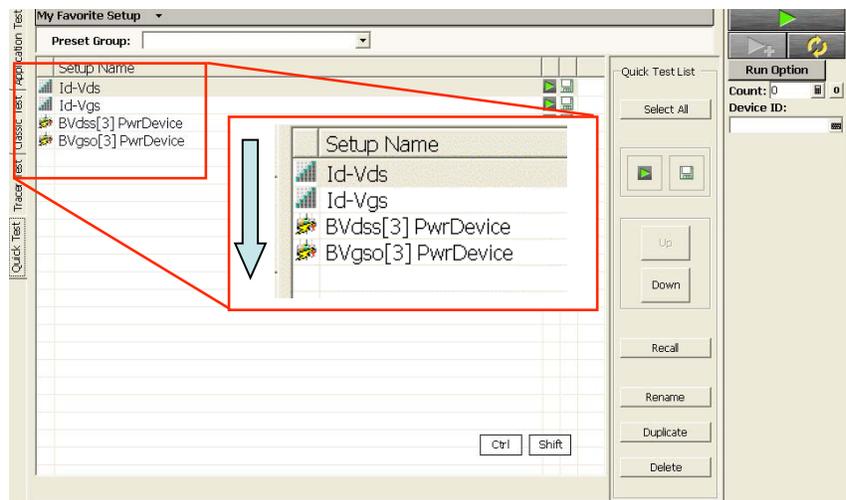

Figure 28. Using the Quick Test feature to execute multiple measurements in sequence.

Data Transportability, Creating Report Quickly

The B1505A's measurement results can be stored (either selectively or automatically) onto a large internal hard disk drive. Since the B1505A's EasyEXPERT software runs on the Microsoft Windows operating system, you can easily export this stored data into PC-compatible spreadsheet formats such as CSV (comma separated values) and XML (extensible markup language). Graphical data can also be saved into PC-compatible picture formats such as Windows bit-map and PNG image files. For example, to export the results on the Tracer Test Mode, just select "Save Data as…" from the file menu and select the format in which to save it as described in Figure 29. The data export function is available for both the Classic Test and Application Test modes, which is important for efficient failure analysis report creation.

In addition to the internal hard disk drive, you can save measurement data onto other storage devices such as network drives and USB storage drives via the B1505A's LAN and USB interfaces (respectively). You can then perform data management and data analysis using Desktop EasyEXPERT running on any Windows-based PC. Desktop EasyEXPERT, which has the same user interface as EasyEXPERT running on the B1505A, can be downloaded for free from Agilent's website. You can also carry out additional data analysis using tools such as Microsoft Excel and you can develop attractive and professional looking failure analysis reports using tools such as Microsoft Word. You can easily print out measurement results such as graphs, data lists, and extracted parameters on any Windows-compatible printer via the LAN or USB interfaces.
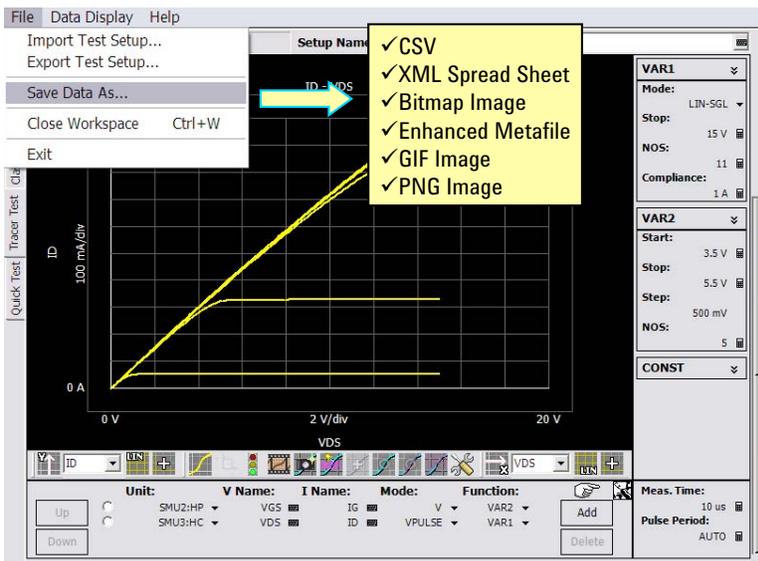

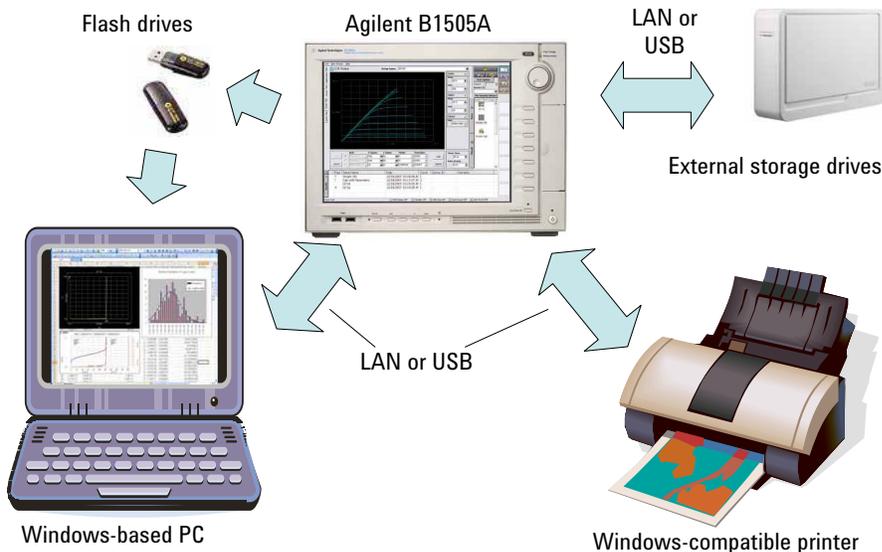*Figure 29. It is easy to export Tracer Test Mode trace data into PC compatible formats.*

Figure 30. Easy and flexible data management.

Conclusion

The B1505A is a new and innovative measurement instrument for power device evaluation. It offers superior measurement and analysis capabilities while retaining the ease-of-use of a conventional curve tracer. In addition, the B1505A's Tracer Test Mode has many tools for quick and easy data analysis that are not available on conventional curve tracers. The Classic Test Mode and Application Test Mode provide more advanced and automated data analysis capabilities, and Quick Test Mode enables the automated testing of multiple devices across a wafer. It is also easy to export data and graphs into a Windows-based PC work environment for further data analysis or to develop documents such as failure analysis reports. The B1505A is an all-in-one solution that meets the needs of failure analysis environments while also improving work efficiency.

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

Agilent Channel Partners

www.agilent.com/find/channelpartners
Get the best of both worlds: Agilent's measurement expertise and product breadth, combined with channel partner convenience.

Microsoft and Windows are U.S. registered trademarks of Microsoft Corporation.

Remove all doubt

Our repair and calibration services will get your equipment back to you, performing like new, when promised. You will get full value out of your Agilent equipment through-out its lifetime. Your equipment will be serviced by Agilent-trained technicians using the latest factory calibration procedures, automated repair diagnostics and genuine parts. You will always have the utmost confidence in your measurements. For information regarding self maintenance of this product, please contact your Agilent office.

Agilent offers a wide range of additional expert test and measurement services for your equipment, including initial start-up assistance, onsite education and training, as well as design, system integration, and project management.

For more information on repair and calibration services, go to:

www.agilent.com/find/removealldoubt

Product specifications and descriptions in this document subject to change without notice.

Agilent Technologies